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Evaluations of shallot genotypes for resistance against fusarium basal rot (*Fusarium oxysporum* f. sp. *cepae*) disease

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ABSTRACT

Fusarium basal rot (FBR) caused by *Fusarium oxysporum* f. sp. *cepae* (*Foc*) is one of the most significant production constraint to shallot. Field experiment was conducted in a naturally *Foc* infested soil at Debre Zeit Agricultural Research Center during 2006 and 2007 cropping seasons to evaluate the level of resistance of sixteen shallot genotypes against FBR disease. Treatments were arranged in randomized complete block design with four replications. The genotypes significantly varied in their susceptibility to FBR and yield. They were grouped into tolerant, moderately and highly susceptible types. Five genotypes (DZ-Sht-168-1A, DZ-Sht-157-1B, Huruta, Negelle and DZ-Sht-169-1b) were identified to be tolerant as they had reduced disease severity levels from 26.8 to 32.5% and increased mean yield by more than 5 t ha^{-1} compared to highly susceptible genotypes (DZ-Sht-076-4, DZ-Sht-201-1C and DZ-Sht-054-3A). Among the tolerant genotypes, DZ-Sht-169-1b had greatly reduced bulb rot incidence by 48% in ground storage and 30% in wire mesh shelf as compared to highly susceptible genotype DZ-Sht-201-1C. The tolerant genotypes have high yielding characteristic, and farmers could adopt them for cultivation where FBR is a problem.

1. Introduction

Shallot (*Allium cepa* L. var. *ascalonicum*) is among the most important vegetable crops in Ethiopia. It is preferred for its shorter growth cycle, better tolerance to drought stresses, and longer storage life than the common onion (*A. cepa*) and also for its distinct flavor that persists after cooking (Currah and Proctor, 1990; Abbey and Fordham, 1998; Rabinowitch and Currah, 2002). It is widely cultivated in different parts of Ethiopia and the total area under shallot and onion is around 17,588 ha with an average shallot yield of about 7.5 t/ha (Aklilu, 1997; CSA (Central Statistics Agency of Ethiopia), 2010).

Like other vegetable crops, shallot is susceptible to a number of foliar, bulb and root fungal pathogens that reduce shallot yield and quality (Rabinowitch and Currah, 2002). Fusarium basal rot (FBR) caused by *Fusarium oxysporum* Schlechtend.:Fr. f. sp. *cepae* H.N. Hans. W.C. Snyder & H.N. Hans. (*Foc*) is one of the most significant constraints to shallot and onion production in Ethiopia and other parts of the world. The FBR is a root and bulb disease of shallot and onion crops and causes heavy losses in the field and during storage (Abawi and Lorbeer, 1972; Lacy and Robert, 1982; Havey, 1995; Brayford, 1996). In addition, FBR affects other *Allium* species, such as, garlic, welsh onion and chives (Stevenson and Heimann, 1981; Kodama, 1983). FBR of shallot is economically important in field production and storage and has been reported from many countries (Tesfaye and Habtu, 1985; Havey, 1995). The symptoms of FBR can be observed on leaves, roots, basal stem plate and bulb scales of mature plants, and dormant bulbs. Losses of 25–35% due to FBR have been reported on onion in USA (Lacy and Robert, 1982). Getachew and Asfaw (2000) indicated that local shallot genotypes from the Hararghe region are more susceptible to FBR than those from other parts of Ethiopia.

In addition to fungicides usage,long-term rotation, tolerant onion varieties and relatively low humidity in storage have been used as control methods of this disease in some countries (Hillocks and Waller, 1997; Cramer, 2000). Currently, some genotypes resistant to FBR are available for intermediate and long-day onion genotypes (Somkuwar et al., 1996). Fungicide treatments can be useful in controlling soilborne infection of the pathogen in genotypes with moderate resistance (Cramer, 2000). However, shallot is grown under low input conditions, continuous seed treatment is not practical for all the farmers and currently no fungicides are registered for control of the disease on shallot in Ethiopia. The ideal and most economical means of managing the disease would be the

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use of FBR resistant genotypes. In addition, the ability of chlamydospores of the fungus to survive in the soil for several years (Brayford, 1996) makes cultural control difficult, emphasizing the need for resistant genotypes. Resistant genotypes offer one of the best non-chemical means for controlling FBR. Research interest is high to obtain shallot genotypes with higher resistance to *Foc* than cultivars released to date (Ozer et al., 2004). The level of resistance in local shallot genotypes is unknown and potential sources of resistance to the disease have not been well studied in Ethiopia (Getachew and Asfaw, 2000). In recent years, due to FBR problem, shallot bulb production area has become decreased in Ethiopia. In view of the above facts, the objective of this study was to evaluate the level of resistance of some shallot genotypes against FBR disease under field conditions.

2. Materials and methods

2.1. Experimental site

Experiments were conducted on 16 shallot genotypes at Debre Zeit Agricultural Research Center (DZARC) during the 2006 and 2007 cropping seasons (from July to November) on alfisols soil that had a high incidence of FBR in previous years (Getachew and Asfaw, 2000). DZARC is located at 8°44′ N latitude and 38°58′ E longitudes at an altitude of 1980 m above sea level. The experimental site has 851 mm mean annual rainfall and about 16.6 °C mean temperature. The experiment was conducted during rainy season on the field previously cropped to shallot for several years and is naturally infested by *Foc*. The *Foc* density per gram of soil was determined from soil samples taken randomly from the experimental field at 15 cm soil depth. The virulence of *Foc* was checked and conducted by pathogenicity test on onion seedlings in pot soil and bulb slices. The pathogen consistently indicated the FBR symptoms. The weather data obtained from experimental site during the field experimental period and storage are presented in Table 1.

2.2. Field experiment

Fifteen shallot genotypes were kindly provided by DZARC and Fedis genotype was purchased from a local market in Harar, Ethiopia. Some of the genotypes are cultivars currently grown by farmers and they are named after districts of major production like Fedis, Huruta, Negelle and Minjar. The shallot seed bulbs were checked for FBR infection using the bulb slice method, and no infection was found. A total of 16 genotypes were evaluated including resistant (Huruta) and susceptible (Fedis) checks (Table 2). Similar size bulb seed was planted by hand on 26 July 2006 and 29 July 2007 and arranged in a randomized complete block design with four replications on 2 m × 2 m (4 m^2) plots with 1 m spacing between blocks, 0.5 m between plots, 0.4 m between rows and 0.2 m between plants. The plot had six rows; 10 plants in a row and a total of 60 plants per plot and were fertilized with 200 kg diammonium phosphate and 150 kg Urea [$CO(NH_2)_2$] ha^{-1}.

Table 1
Weather data at Debre Zeit agricultural Research Center, Ethiopia during July to November 2006 and 2007.[a]

Year	Rainfall (mm)	Mean relative humidity (%)	Mean maximum temperature (°C)	Mean minimum temperature (°C)
2006	302	60.2	24.78	11.46
2007	362.6	64.5	26.46	10.48

[a] Mean maximum and minimum room temperature recorded from1 January to 30 March 2007 and 2008 for ground and wire mesh bulb storage condition were 25 °C, 15 °C and 24 °C, 17 °C respectively.

Table 2
Incidence of Fusarium basal rot on shallot genotypes under field condition during the 2006 and 2007 crop season.[a]

Genotype	Initial disease incidence (%)[b]		Mean of two years (%)	Final disease incidence (%)[c]		Mean of two years (%)
	2006	2007		2006	2007	
Negelle	0.9 g	1.6 bc	1.3 d	16.5 ef	12.7 def	14.6 de
Huruta	1.0 fg	1.2 c	1.1 d	15.3 f	13.7 def	14.5 de
Minijar local	3.6 a	1.6 bc	2.6 ab	23.5 a–e	16.5 c–f	20.0 bcd
Fedis	3.2 ab	2.0 abc	2.6 ab	23.9 a–e	21.0 a–e	22.4 abc
DZ-Sht-232-1C	2.9 abc	2.2 abc	2.6 ab	19.9 b–f	14.5 def	17.2 cde
DZ-Sht-168-1A	1.9 d–g	1.4 c	1.6 cd	15.5 f	12.0 f	13.7 e
DZ-Sht-167-1A	3.3 ab	2.4 abc	2.8 ab	24.8 a–d	24.2 abc	24.5 ab
DZ-Sht-076-4	3.5 a	2.7 ab	3.1 a	27.2 ab	27.7 a	27.5 a
DZ-Sht-169-1b	1.9 c–f	1.6 bc	1.8 cd	17.6 def	12.2 ef	14.9 de
DZ-Sht-305-2A	2.0 cde	1.5 c	1.8 cd	19.1 c–f	16.2 c–f	17.7 cde
DZ-Sht-165-1	1.1 efg	1.6 bc	1.4 d	21.2 a–f	13.5 def	17.3 cde
DZ-Sht-201-1C	3.1 ab	1.9 abc	2.5 ab	26.1 abc	25.3 ab	25.7 ab
DZ-Sht-157-1B	1.1 efg	1.6 bc	1.4 d	16.0 f	12.7 def	14.4 de
DZ-Sht-101-4A	2.4 bcd	2.2 abc	2.3 bc	20.5 b–f	13.0 def	16.7 cde
DZ-Sht-276-2	3.5 a	2.9 a	3.2 a	25.0 a–d	17.0 b-f	21.0 bc
DZ-Sht-054-3A	3.7 a	2.0 abc	2.9 ab	28.2 a	21.5 a–d	24.9 ab

[a] Means within a column followed by different letters are significantly different at $P \leq 0.05$ according to Duncan Multiple Range Test (DMRT).
[b] Initial disease assessment at 38 days after planting (DAP).
[c] Final disease assessment at 108 DAP.

All shallot trial plots were treated with fungicides Penncozeb 80WP 2.5 kg ha^{-1} [(mancozeb), Cerexagri Inc., King of Prussia, Pennsylvania, USA] and Ridomil Gold GW 68 2.5 kg ha^{-1} [(metalaxyl-M 4% + mancozeb 64%), Syngenta AG, Basel, Switzerland] against downy mildew (*Peronospora destructor*). For control of onion thrips (*Thrips tabaci*), insecticide Karate (lambda-cyhalothrin 25 EC, Syngenta AG, Basel, Switzerland) at a rate of 0.5 l ha^{-1} was used at 52 days after planting (DAP). Weeding and cultivation were managed by hand.

2.3. Disease assessment

Fusarium bulb rot incidence (percent of diseased plants) was assessed six times at a 14-day interval beginning from first appearance of the disease in the plots. A few FBR infected plants randomly rouged out and isolated *Foc* under laboratory condition. The number of infected plants was counted in all rows of each plot at 38, 52, 66, 80, 94 and 108 DAP in both cropping seasons. At harvest, from the central four rows of each plot, infected plants were selected and bulb basal rot were examined for disease severity using a 1–5 scale where 1 = without symptoms, 2 = up to 10% rotted roots, 3 = 10–30% rotted roots with up to 10% rotted basal plates, 4 = completely rotted roots and 10–30% rotted basal plates, and 5 = completely rotted roots and more than 30% rotted basal plates (Rengwalska and Simon, 1986). FBR severity scores were converted into percentage severity index (PSI) as

$$\text{PSI} = \text{sum of numerical ratings} \times 100/\text{No.of plants scored} \times \text{Maximum score on scale.}$$

The area under the disease progress curve (AUDPC) was calculated for each treatment from the assessment of disease incidence using the formula:

$$\text{AUDPC} = \sum_{i=1}^{n-1} [1/2(X_i + X_{i+1})][t_{i+1} - t_i]$$

Where X_i is the disease incidence in percent at initial assessment, t_i is the time of the first assessment in days from the first

assessment date and n is the total number of days disease was assessed (Campbell and Madden, 1990).

After harvest, infected bulbs were cut longitudinally and the percentage of bulb decay for each genotype was determined. Cull bulbs that were severely affected by FBR disease were recorded from each plot.

2.4. Yield

Initial plant stand count in each plot was recorded at 45 DAP. Bulbs were harvested on 116 and 120 DAP in the first and the second seasons, respectively. Shallot yield was measured by harvesting from four middle rows of each plot excluding two border rows on both sides to avoid the border effects. The yield was harvested according to the genotype characteristics maturity. Harvested shallot bulbs were cured on wire mesh shelves for 10 days before weight was taken.

2.5. Storage bulb rot assessment

Incidence of bulb rot on ground and wire mesh storage was assessed for three months. Apparently 40 healthy medium sized bulbs from each replication of every genotype were placed on ground and wire mesh storage at ambient room temperature conditions for three months and each bulb was examined for symptoms of FBR at a 15-day interval. The percentage of bulb decay due to FBR from the total stored bulbs per replicate was assessed as incidence of bulb rot.

2.6. Data analyses

Analyses of variance (ANOVA) for the effects of genotypes on FBR incidence, severity (PSI), AUDPC, yield, plant stand count, cull bulbs and bulb rot incidence from storage were used to compare the level of resistance among evaluated genotypes. All analyses were performed using statistical package SAS, version 9 (SAS institute Inc, 2002). Mean separation was done by Duncan's multiple-range test.

3. Results

3.1. Disease incidence

Weather conditions for FBR epidemic development were very favorable during the two years (Table 1). The first symptoms (yellowing to severe chlorotic leaves and stunting) were observed at 38 DAP both in 2006 and 2007. Initial and final disease incidences were significantly different among treatments ($P \leq 0.05$) in both cropping seasons (Table 2). The initial incidence recorded on DZ-Sht-054-3A, Minjar Local, DZ-Sht-276-2 and DZ-Sht-076-4 genotypes was significantly different from Negelle, Huruta, DZ-Sht-165-1, DZ-Sht-157-1B, DZ-Sht-168-1A, DZ-Sht-169-1B, DZ-Sht-305-2A and DZ-Sht-101-4A in 2006. During 2007, genotypes DZ-Sht-276-2 with 2.9% and DZ-Sht-076-4 with 2.7% showed higher initial disease incidence and significantly different from Huruta (1.2%), DZ-Sht-168-1A (1.4%) and DZ-Sht-305-2A (1.5%). According to the mean value of initial disease of the two years, genotypes DZ-Sht-076-4, DZ-Sht-201-1C, DZ-Sht-054-3A, DZ-Sht-276-2, Fedis, DZ-Sht-167-1A, Minjar Local and DZ-Sht-305-2A were significantly different from DZ-Sht-168-1A and DZ-Sht-157-1B, DZ-Sht-169-1b, Huruta and Negelle.

In 2006, Huruta, DZ-Sht-168-1A and DZ-Sht-157-1B showed lower FBR final disease incidence than DZ-Sht-054-3A, DZ-Sht-076-4, DZ-Sht-201-1C, DZ-Sht-276-2, DZ-Sht-167-1A, Fedis and Minjar Local. Genotypes with highest incidence exhibited considerable infection during growing periods of August and September months. In 2007, the higher final disease incidence was recorded on DZ-Sht-076-4, DZ-Sht-201-1C and DZ-Sht-167-1A, while the lower final incidence was recorded on DZ-Sht-168-1A followed by DZ-Sht-169-1B, DZ-Sht-157-1B, Negelle, DZ-Sht-101-4A, DZ-Sht-165-1, Huruta and DZ-Sht-232-1C. The average mean value of final disease incidence was low on DZ-Sht-168-1A, DZ-Sht-157-1B, DZ-Sht-169-1b, Huruta and Negelle, and statistically different from DZ-Sht-076-4, DZ-Sht-201-1C, DZ-Sht-054-3A, DZ-Sht-276-2, Fedis and DZ-Sht-167-1A. Huruta, DZ-Sht-168-1A, DZ-Sht-157-1B and Negelle consistently showed lower incidence levels in both years. Although the level of incidence in 2007 was generally lower than in 2006, similar relative levels of susceptibility of the genotypes were observed over the two years.

3.2. Disease severity and cull bulbs

Evaluation of reactions of the 16 shallot genotypes to FBR at harvest time in 2006 indicated that DZ-Sht-054-3A and DZ-Sht-201-1C were highly susceptible and their disease severity was ranged from 26.5 to 27.1%, while the disease severity of tolerant genotypes DZ-Sht-157-1B and DZ-Sht-168-1A ranged from 17.1 to 17.5% (Table 3). In 2007, disease severity on highly susceptible genotypes DZ-Sht-076-4 and DZ-Sht-201-1C ranged from 25.8 to 26.0%, while the lower disease severity was from the tolerant genotypes DZ-Sht-169-1b (15.9%) and DZ-Sht-168-1A (16.9%). High disease severity was recorded on DZ-Sht-201-1C, while DZ-Sht-168-1A consistently had low severity.

Based on the mean disease severity value of the two years, DZ-Sht-076-4, DZ-Sht-201-1C, DZ-Sht-054-3A, DZ-Sht-276-2, Fedis, DZ-Sht-167-1A and Minjar Local showed significantly higher susceptibility than DZ-Sht-168-1A and DZ-Sht-157-1B. Tolerant genotypes DZ-Sht-169-1b, Huruta and Negelle were statistically different from DZ-Sht-076-4 and DZ-Sht-201-1C. DZ-Sht-101-4A, DZ-Sht-232-1C, DZ-Sht-165-1 and DZ-Sht-305-2A were classified into the moderately susceptible group (Table 3).

The percentage of FBR infected cull bulbs based on the total number of harvested bulbs is presented in Table 3. Significant differences ($P < 0.01$) were found among evaluated genotypes at the harvest time in both cropping seasons. High cull bulbs were recorded from DZ-Sht-054-3A (3.4%) and DZ-Sht-076-4 (3.3%), while low cull bulbs were from Negelle, DZ-Sht-168-1A, Huruta,

Table 3
Fusarium bulb rot severity and cull bulb on shallot genotypes during 2006 and 2007 cropping season.[a]

Genotype	Disease severity (%)		Mean of two years (%)	Cull bulb (%)		Mean of two years (%)
	2006	2007		2006	2007	
Negelle	20.2 a–d	17.2 bcd	18.7 cd	1.2 d	1.2 d	1.2 e
Huruta	18.0 bcd	19.4 a–d	18.7 cd	1.7 cd	2.0 bcd	1.8 cde
Minijar local	24.9 a–d	23.7 a–d	24.3 abc	2.1 a–d	2.6 a–d	2.4 bcd
Fedis	25.0 a–d	24.3 a–d	24.7 abc	2.2 a–d	2.7 a–d	2.4 a–d
DZ-Sht-232-1C	22.8 a–d	21.6 a–d	22.2 a–d	2.0 bcd	2.3 a–d	2.1 b–e
DZ-Sht-168-1A	17.5 cd	16.9 cd	17.2 d	1.2 d	1.8 cd	1.5 de
DZ-Sht-167-1A	23.7 a–d	25.6 abc	24.6 abc	2.7 abc	2.7 abc	2.7 abc
DZ-Sht-076-4	26.3 abc	26.0 a	26.2 a	3.3 ab	3.4 ab	3.3 a
DZ-Sht-169-1b	22.5 a–d	15.9 d	19.2 bcd	1.9 cd	1.2 d	1.6 de
DZ-Sht-305-2A	22.7 a–d	22.5 a–d	22.6 a–d	1.9 cd	2.6 a–d	2.2 bcd
DZ-Sht-165-1	23.9 a–d	17.8 a–d	20.8 a–d	2.5 a–d	2.1 a–d	2.3 bcd
DZ-Sht-201-1C	26.5 ab	25.8 ab	26.1 a	2.2 a–d	3.5 a	2.9 ab
DZ-Sht-157-1B	17.1 d	18.4 a–d	17.7 d	1.9 cd	1.9 cd	1.9 cde
DZ-Sht-101-4A	23.7 a–d	21.5 a–d	22.6 a–d	2.1 a–d	2.1 a–d	2.1 b–e
DZ-Sht-276-2	25.2 a–d	24.4 a–d	24.8 ab	3.1 abc	2.9 abc	2.9 ab
DZ-Sht-054-3A	27.1 a	23.9 a–d	25.5 ab	3.4 a	2.7 abc	3.1 ab

[a] Means within a column followed by different letters are significantly different at $P < 0.05$ according to Duncan Multiple Range Test (DMRT).

DZ-Sht-169-1b, DZ-Sht-305-2A and DZ-Sht-157-1B in 2006. In 2007, high cull bulbs were recorded from DZ-Sht-201-1C and DZ-Sht-076-4, and the levels were significantly different from those of tolerant genotypes DZ-Sht-169-1b, Negelle, DZ-Sht-168-1A and DZ-Sht-157-1B. The two-year average data showed that tolerant genotypes, DZ-Sht-169-1b, Negelle, DZ-Sht-168-1A, Huruta and DZ-Sht-157-1B, were significantly different from highly susceptible genotypes DZ-Sht-076-4, DZ-Sht-054-3A, DZ-Sht-201-1C and DZ-Sht-276-2 in infected cull bulb number. Overall, among all genotypes Negelle consistently showed the lowest cull bulb number, while DZ-Sht-076-4 had the highest.

3.3. AUDPC

There were significant differences ($P < 0.001$) among genotypes for AUDPC in both seasons. Based on disease incidence, tolerant genotypes were all with AUDPC value ranging from 8.8 to 10.4% in 2006 and from 7.6 to 8.05% in 2007 (Fig. 1). The two-year mean AUDPC value was high on DZ-Sht-076-4, DZ-Sht-201-1C, DZ-Sht-054-3A, DZ-Sht-167-1A, and Fedis. Among the tolerant genotypes, DZ-Sht-168-1A, Huruta, Negelle, DZ-Sht-157-1B and DZ-Sht-169-1b were not significantly different from each other in AUDPC value.

3.4. Yield

After 45 days of planting the percentage of plant stand ranged from 58 to 79% in 2006, while in 2007 it was from 55 to 86% per plot. During both cropping seasons, the shallot plant stands were significantly different ($P \leq 0.05$) among genotypes (Table 4). The percentages of plant stand of Negelle and DZ-Sht-157-1B were statistically different from those of DZ-Sht-276-2 and DZ-Sht-054-3A in 2006. In 2007, only DZ-Sht-157-1B was statistically different from DZ-Sht-076-4. The two-year average percentages of plant stand of DZ-Sht-157-1B, Negelle, Huruta and DZ-Sht-305-2A were significantly higher than those of DZ-Sht-054-3A and DZ-Sht-076-4.

Significant differences ($P < 0.01$) for bulb yield were observed among genotypes (Table 4). DZ-Sht-168-1A and DZ-Sht-157-1B produced the highest bulb yield. In 2006, the average yields of DZ-Sht-168-1A and DZ-Sht-157-1B were 1.5–2.0 fold higher than the three susceptible genotypes DZ-Sht-076-4, DZ-Sht-276-2 and DZ-Sht-054-3A. In 2007, low yield was from highly susceptible genotypes, DZ-Sht-076-4, DZ-Sht-167-1A, DZ-Sht-054-3A, DZ-Sht-201-1C and Fedis. In contrast, yields of Negelle and DZ-Sht-169-1b were similarly higher than those of the susceptible genotypes. The two-year average yields of highly susceptible genotypes DZ-Sht-054-3A, DZ-Sht-076-4, DZ-Sht-167-1A, DZ-Sht-276-2, Fedis and DZ-Sht-201-1C were significantly lower than those of tolerant genotypes DZ-Sht-168-1A, Negelle, DZ-Sht-169-1b, DZ-Sht-157-1B and Huruta. DZ-Sht-101-4A and DZ-Sht-165-1 had comparable two-year mean yields to DZ-Sht-232-1C. There was a wide range in yield, with DZ-Sht-168-1A, Negelle and DZ-Sht-169-1b producing higher yields than all of the other genotypes.

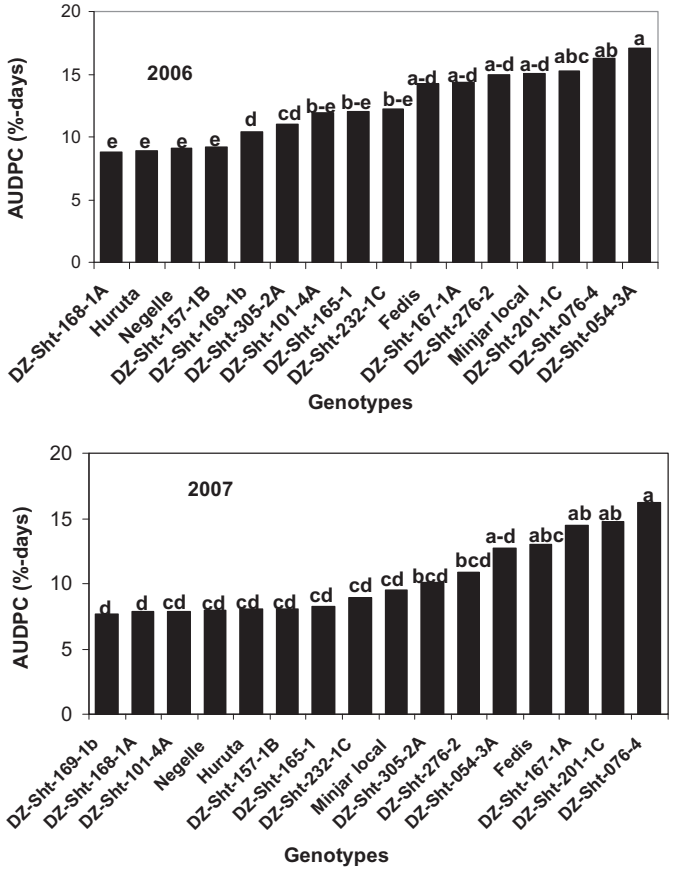

Fig. 1. Area under disease progress curve (AUDPC) for fusarium basal rot on sixteen shallot genotypes, during 2006 and 2007 year.

3.5. Effects of storage condition on fusarium basal rot

The data of bulb rot incidence under an ambient ground and wire mesh shelf storage conditions experiments for a three-month period were summarized in Table 5. In the ground storage experiment, bulb rot due to FBR was significantly different among genotypes ($P \leq 0.05$) for both years. In 2007, losses due to bulb rot in the ground storage were significantly less in DZ-Sht-169-1b, DZ-Sht-165-1 and DZ-Sht-305-2A compared to highly susceptible genotypes DZ-Sht-167-1A, DZ-Sht-276-2 and Fedis. In the 2008 ground storage experiment, high bulb rot incidences were recorded on DZ-Sht-167-1A, DZ-Sht-201-1C, DZ-Sht-276-2, DZ-Sht-305-2A, DZ-Sht-076-4 and DZ-Sht-054-3A, which were statistically different from those of DZ-Sht-101-4A, DZ-Sht-169-1b, Huruta, DZ-Sht-165-1 DZ-Sht-168-1A, Negelle and DZ-Sht-

Table 4
Mean percent initial plant stand and yield of shallot genotypes at Debre Zeit during 2006 and 2007 cropping seasons.[a]

Genotype	Plant stand (%)[b]		Mean of two years (%)	Yield (t/ha)		Mean of two years (t/ha)
	2006	2007		2006	2007	
Negelle	78.7 a	78.7 ab	78.7 a	11.7 a–d	15.3 a	13.5 ab
Huruta	76.5 abc	80.5 ab	78.5 a	12.3 abc	11.7 abc	12.0 abc
Minijar local	74.2 abc	80.5 ab	77.4 ab	9.6 cde	9.2 bcd	9.4 cde
Fedis	73.5 abc	70.5 ab	72.0 abc	9.4 cde	7.6 cd	8.5 de
DZ-Sht-232-1C	75.5 abc	78.5 ab	77.0 ab	11.1 bcd	10.8 a–d	10.9 a–d
DZ-Sht-168-1A	75.7 abc	78.0 ab	76.9 ab	14.8 a	13.6 ab	14.2 a
DZ-Sht-167-1A	75.7 abc	77.7 ab	76.7 ab	9.4 cde	6.6 cd	8.0 de
DZ-Sht-076-4	73.0 bc	55.0 b	64.0 bc	8.6 cde	5.7 d	7.2 e
DZ-Sht-169-1b	76.2 abc	78.0 ab	77.1 ab	11.6 a–d	15.1 a	13.4 ab
DZ-Sht-305-2A	76.5 abc	80.0 ab	78.2 a	11.4 a–d	9.5 a–d	10.5 bcd
DZ-Sht-165-1	75.7 abc	75.7 ab	75.7 ab	11.6 a–d	10.5 a–d	11.0 a–d
DZ-Sht-201-1C	76.0 abc	60.5 ab	68.2 abc	10.2 cde	7.0 cd	8.6 de
DZ-Sht-157-1B	78.5 ab	85.5 a	82.0 a	13.9 ab	12.0 abc	12.9 ab
DZ-Sht-101-4A	76.5 abc	78.0 ab	77.2 ab	10.8 bcd	11.6 abc	11.2 a–d
DZ-Sht-276-2	72.5 c	76.7 ab	74.6 ab	8.3 de	8.6 bcd	8.2 de
DZ-Sht-054-3A	58.2 d	62.5 ab	60.4 c	6.9 e	7.0 cd	6.9 e

[a] Means within a column followed by different letters are significantly different at $P \leq 0.05$ according to Duncan Multiple Range Test (DMRT).
[b] Initial plant stand at 45 days after planting.

Table 5
Effects of storage conditions on mean percent Fusraium basal rot incidence during 2007 and 2008.[a]

Genotype	Ground storage bulb rot incidence (%)		Mean of two years (%)	Wire mesh storage bulb rot incidence (%)		Mean of two years (%)
	2007	2008		2007	2008	
Negelle	42.8 abc	30.3 bcd	36.5 cde	28.2 de	30.3 ab	29.2 c–g
Huruta	45.1 ab	22.8 d	33.9 def	38.7 a–d	24.2 dc	31.4 b–e
Minijar local	48.7 ab	41.5 ab	45.1 ab	42.2 abc	23.7 cde	32.9 a–d
Fedis	50.2 a	39.2 abc	44.6 abc	26.7 de	31.1 ab	28.9 c–g
DZ-Sht-232-1C	47.9 ab	34.5 abc	41.2 a–d	36.7 a–d	23.4 cde	30.1 c–f
DZ-Sht-168-1A	44.5 ab	29.8 cd	37.2 b–e	37.2 a–d	19.3 de	28.3 c–g
DZ-Sht-167-1A	51.1 a	45.7 a	48.4 a	37.6 a–d	33.4 a	35.5 abc
DZ-Sht-076-4	47.2 ab	42.9 a	45.1 ab	42.7 abc	32.5 a	37.6 ab
DZ-Sht-169-1b	26.0 d	22.4 d	24.2 g	36.5 a–d	19.3 de	27.9 d–g
DZ-Sht-305-2A	37.7 bc	45.3 a	41.5 a–d	29.1 cde	18.2 e	23.6 fg
DZ-Sht-165-1	32.7 cd	22.8 d	27.7 fg	18.7 e	26.1 bc	22.4 g
DZ-Sht-201-1C	47.8 ab	45.7 a	46.8 a	47.2 a	32.7 a	39.9 a
DZ-Sht-157-1B	40.6 abc	31.2 bcd	35.9 de	36.9 a–d	28.9 abc	32.9 a–d
DZ-Sht-101-4A	39.2 abc	22.3 d	30.8 efg	30.6 b–e	18.7 de	24.7 efg
DZ-Sht-276-2	51.0 a	45.3 a	48.1 a	38.0 a–d	32.4 a	35.2 abc
DZ-Sht-054-3A	47.6 ab	42.6 a	45.1 ab	44.2 ab	30.9 ab	37.5 ab

[a] Means within a column followed by different letters are significantly different at $P \leq 0.05$ according to Duncan Multiple Range Test (DMRT).

157-1B. The two-year mean incidence values of DZ-Sht-169-1b, DZ-Sht-165-1 and DZ-Sht-101-4A, Huruta, DZ-Sht-157-1B and Negelle were significantly lower than those of highly susceptible genotypes DZ-Sht-167-1A, DZ-Sht-276-2, DZ-Sht-201-1C, DZ-Sht-076-4, Minjar Local and DZ-Sht-054-3A.

In the mesh shelf storage trials, significant differences among treatments ($P \leq 0.05$) were also detected (Table 5). Almost half of the genotypes had similar incidences of rotted bulbs in wire mesh storage at the ambient temperature condition in 2007. The lowest bulb-rot was recorded from DZ-Sht-165-1 (18.7%). High bulb rot incidences were recorded for DZ-Sht-201-1C (47.2%), DZ-Sht-054-3A (44.2%), DZ-Sht-076-4 (42.7%) and Minjar Local (42.2%), which were statistically different from DZ-Sht-165-1, Fedis and Negelle. In 2008, high bulb rot incidences were obtained from DZ-Sht-167-1A, DZ-Sht-201-1C, DZ-Sht-076-4 and DZ-Sht-276-2, while lower bulb rot incidences were recorded for DZ-Sht-305-2A, DZ-Sht-101-4A, DZ-Sht-169-1b and DZ-Sht-168-1A.

The two-year mean incidence values of DZ-Sht-165-1, DZ-Sht-305-2A, DZ-Sht-101-4A, DZ-Sht-169-1b, DZ-Sht-168-1A and Negelle were significantly lower than those of DZ-Sht-201-1C, DZ-Sht-076-4 and DZ-Sht-054-3A.

4. Discussion

The evaluated genotypes are grouped as highly susceptible, moderate and tolerant types in their reaction to FBR. Both resistant and susceptible cultivars showed similar infection rates of roots and basal plates by *Foc* (Havey, 1995; Cramer, 2000). Getachew and Asfaw (2000) found that genotype Fedis from the Hararghe region was more susceptible to FBR than those collected from other areas. The present study also confirmed that Fedis was highly susceptible. In both seasons, FBR incidence ranged from 12 to 28.2%. In the USA, the FBR incidence for fall planted onion genotypes ranged from 0.6% to 40.3% while for spring planted genotypes ranged from 2.9% to 29.2% (Cramer et al., 2000). The tolerant shallot genotypes were consistently showed a low FBR incidence level. At DZARC, genotypes Huruta and Negelle proved to be grown successfully in loam and clay soils where FBR previously has been a problem (Getachew and Asfaw, 2000). These tolerant genotypes could be used as valuable sources for breeding programs to enhance resistance in shallot crops against FBR disease.

Discoloration to a certain degree is a measure of infection because the fungus was invariably isolated from tissues, but usually not from the bulb scales. This suggests that the movement of the fungus from the stem plate tissues to bulb scales was essential for the development of the basal rot stage of the disease. Abawi and Lorbeer (1971) indicated that tolerant genotypes might differ from susceptible ones by possessing a factor, which restricts further advance of the fungus. The factors operating in tolerant genotypes could be physical or physiological or a combination of both. Cramer (2000) revealed that FBR infection depends upon the time of year, environmental condition, genotype and level of inoculum. Although levels of infection by *Foc* in 2006 were generally higher than those observed in 2007, similar levels of susceptibility of the genotypes were observed during two years.

Tolerant genotypes showed lower level of disease severity on bulbs at harvest time than highly susceptible genotypes. DZ-Sht-168-1A consistently showed the lowest percent severity in the two-year trials. Lorbeer and Stone (1965) and Cramer (2000) also reported the occurrence of variable susceptibility of onion varieties to infection by *Foc* over years. The results of both studies suggested that the susceptibility of the varieties tested was quantitative in nature and did not show a clear-cut for FBR reactions.

Many of the bulbs on DZ-Sht-076-4 and DZ-Sht-054-3A had partially to complete decay in the stem plate and lower bulb scale regions during the last few weeks of plant growth before bulb harvest. There were more rotted bulbs in the highly susceptible than tolerant genotypes at harvest time. A notable symptom of FBR, separation of roots from the bulb at the stem plate during uprooting, was observed at harvest time. Plots with a history of the disease mostly had the highest populations of the fungus. The DZARC site was consistently revealed high populations of *Foc* (an average of 6500 propagules/g oven-dry soil). But in some cases there was evidence of biotic or abiotic effects where fields with high populations of *Foc* did not have a high incidence of FBR, even when susceptible cultivar of onion was grown (Abawi and Lorbeer, 1971). There are also suppressive and conducive soils that affect the incidence of diseases caused by Fusarium wilt fungi (Mace et al., 1981).

Significant yield differences among genotypes were found in both seasons. Variations in yield might have depended on establishment of seedling, disease level and yield potential of genotype. Yields were consistently greater for DZ-Sht-168-1A, Negelle and DZ-Sht-169-1b compared to other genotypes. The higher yield obtained from these genotypes were due to reduced FBR infection and the production of better vegetative growth and larger bulbs. Genotypes DZ-Sht-054-3A, DZ-Sht-076-4, DZ-Sht-167-1A, Fedis, DZ-Sht-276-2 and DZ-Sht-201-1C had low initial stand counts and yields. The low numbers of initial stand and production of smaller bulbs also might contribute to the low yield in highly susceptible genotypes. As indicated by Lacy and Robert (1982), *Foc* appeared to have an important influence on yields in infested plots. The tolerant genotypes exhibited higher yield in heavy infested fields, while the highly susceptible genotypes produced low yields.

Fusarium basal rot causes reduction in bulb weight and number of marketable bulbs in field and storage. Cramer (2000) indicated that onions that are evaluated for *Foc* resistance should be screened both during field growth and the post harvest period. The disease becomes a problem in storage where it may continue until the bulbs are completely destroyed. Considering the level of storage rots in 2006, DZ-Sht-169-1b was twice effective in reducing basal rot levels compared to genotypes DZ-Sht-167-1A and DZ-Sht-276-2 under the ground storage condition. McClellan (1952) indicated that FBR developed most rapidly at 25–30 °C. The bulb rot incidence during 2007 was higher than 2008. Mean room maximum average temperature in the first year was 25 °C, while in the second year storage trial it was 24 °C (Table 1). Two years mean bulb rot

indicated that the identified tolerant genotypes had lower bulb rot in both ground and mesh storage compared to the highly susceptible genotypes except Fedis. The progress of bulb rots in wire mesh storage appeared lower than in ground storage, presumably due to well air circulation conditions.

FBR epidemics and bulb rot in storage significantly varied among storage type and years. Brayford (1996) indicated that losses of FBR during storage were greater than losses in the field. Bulb rot incidences in the storages were higher than the field. In India, the incidence of FBR under storage condition ranged from 20 to 80%, in Brazil from 12 to 75% of (Somkuwar et al., 1996). Also apparently healthy bulb with minor infection of basal plate placed in storage pathogen growth continues during storage until the entire bulb becomes unmarketable, most of the damage from FBR is observed during storage (Havey, 1995; Stadnik and Dhingra, 1996).

The prevalence of FBR varied among shallot genotypes. The evaluated shallot genotypes differed significantly in disease severity, percent diseased plants, bulb yields and bulb rots. The findings of the present study indicated that the pathogen showed significant effect in reducing the yield of shallot by creating higher disease severity. The best tolerant sources were genotypes DZ-Sht-168-1A, DZ-Sht-157-1B, Huruta, Negelle and DZ-Sht-169-1b. Tolerant shallot genotypes that are widely adapted to the environmental conditions should be grown. Further studies on disease reactions of shallot genotypes and agronomic traits should be conducted to develop improved varieties for the future.

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